Advances In Biomedical Research. Over the next two decades we will experience truly revolutionary advances in our basic biomedical knowledge, including our knowledge of diseases. This better understanding of the biochemistry of health and disease states will allow the development of more refined biological markers for most diseases. We will use these biological markers to learn much more every time we do a blood test. Genetic markers -- our "DNA fingerprint" -- will become part of our medical records as mapping the human genome gives us the capacity to identify genetic predispositions to many diseases. Better technologies for scanning and non-invasive monitoring will improve diagnostics. Data from these advanced forms of monitoring will allow early alerts of the need to make lifestyle changes, and early treatment. For example, it will become much easier to identify cancer or heart conditions before they can do serious damage.

The operation of the "chemical factory" in our body is as unique as our finger prints are unique. Yet medical care can not, as yet, treat us as "biochemically unique" persons. These advances in basic biomedical knowledge will allow the biochemical uniqueness of each individual to be more fully incorporated into medical practice. "Mass treatment," where everyone is treated in a standardized way, will increasingly give way to "customized treatment" that takes into account individual genetics, biochemical uniqueness and health history.

These three factors -- disease prevention and health promotion, the growing importance of home care, and advances from basic research -- all interweave in the development of a more advanced home health care environment.

A Model of Advanced Home Health Care

As health care increasingly emphasizes prevention, care of chronic conditions, and reassurance and informational support, the delivery of health care to the home becomes an increasingly significant health care strategy.

Home care can make the difference in some cases of enabling patients to remain in their homes instead of having to go to a hospital or nursing home.

Patients coming out of hospitals or experiencing outpatient procedures typically require various regimens and therapies at home which used to be part of their hospital stay. If their conditions are chronic or long term, their home care needs can extend over long periods of time. For home bound patients, patient to patient support groups are becoming a growing prescription to reduce isolation and provide reassurance.

If home care workers are needed, supervision of these workers is essential both for quality control and for maintaining home worker morale in what can be isolating and frustrating work.

Many of these patient and home worker needs can be met by creating electronic links between patients and their health care professionals, between home workers and their supervisors and between patients and families. The ability to talk directly with health care professionals is important for getting medical advice, avoiding the inconvenience and expense of unnecessary office visits, and receiving assurance from authoritative sources. In many situations, asynchronous communication -- the ability to leave messages and receive answers -- can be faster and more convenient for this kind of communication both for busy professionals and for house bound patients. Such electronic forms of consultation can be efficient for doctors in terms of time and staff and efficient to consumers in terms of ease of access.

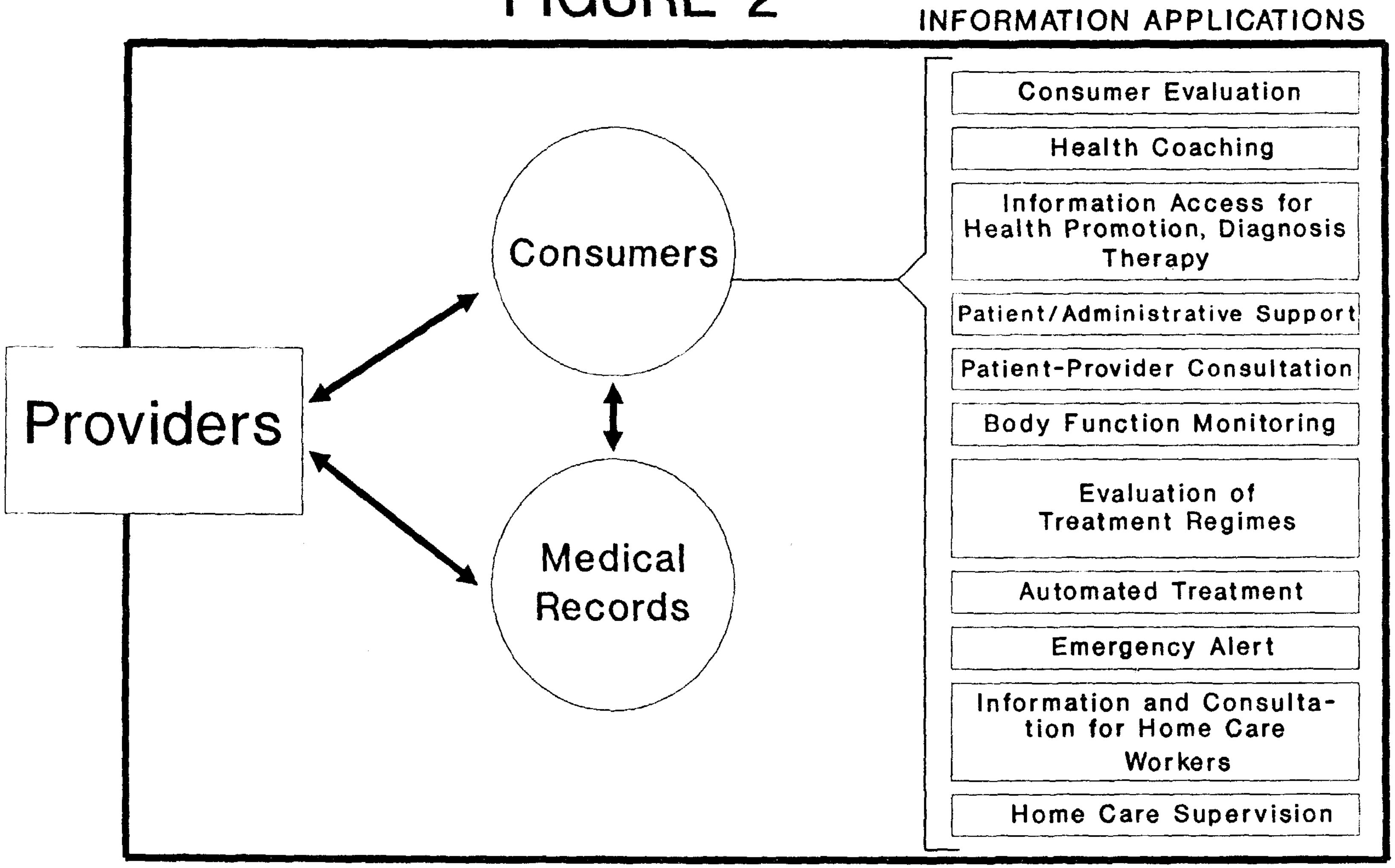
Two-way video can greatly enhance these contacts, **especially where emotional assurance or motivation is important.** Physicians can observe their patients' body language and facial demeanor. Members of patient or family support groups can feel more socially connected. Patients can be shown visually how to use their wheel chair, how to go up and down stairs or how to take their medication. Visual and graphic interactive communications are far more effective in motivating and educating patient behaviors than detailed instruction sheets and pamphlets on nutrition and wellness. While video will never be a total substitute for direct face to face physician/ patient contacts, it can substantially augment these contacts and in many cases save the patient the inconvenience and hardship which can be involved in making an office visit. For patients without regular physicians, electronic contacts along with face-to-face contact with their families or home care workers can provide a service otherwise not realistically available to them. Using video, a physician can guide a home health worker to place various body function monitoring instruments properly to enable the doctor to better observe a home patient's condition.

Finally, physicians, HMOs and other organizations can increasingly provide convenient electronic services such as appointment scheduling, automated insurance claim filing, and information on eligibility, benefits and costs.

Figure 2 illustrates a general model of the kind of advanced home health care environment that we believe can emerge over the decades just ahead. The various information technology applications in this model are described briefly below.

ADVANCED HOME HEALTH CARE

FIGURE 2



Emerging Technologies For Home Care

Powerful new information technology applications are emerging which can make home based health care surprisingly effective. Several types of health information technologies will move into the home over the next few years and be fully established by 2000-2010.[8]

Computer Based Medical Records. Computer based medical records are a "foundation technology" that will make possible a wide range of new applications. They will record and store all patient information including patient problems, test results, orders submitted, treatment plans, X-rays and other images. Over time, they will incorporate new types of information such as personal "DNA fingerprints," providing information on genetic proclivities to disease. Electronic records will be "in the home" in a real sense. They will be stored on credit-card sized "patient cards" as well as in home and provider information systems. Individuals will have electronic access to their records and will be able to add to the records from home, for example by entering the results of home tests or various kinds of body function monitoring. By the late 1990s, other home health applications will interact with electronic medical records.

As medical record information is increasingly put into electronic form, it can be readily aggregated and analyzed. This kind of data analysis will let us identify patterns we could not possibly have seen before such as the cost-effectiveness and comparative medical outcomes of different treatments and therapies. The resulting information will give doctors a more scientific basis for assessing "what works," and will help consumers evaluate alternative therapies and providers.

When information from medical records is collected for analysis, it will be absolutely critical to safeguard personal privacy by insuring that no names or other personally identifying information are attached. Nothing could retard the development of computer-based patient records as severely as privacy controversies resulting from a failure to develop and apply appropriate safeguards for medical record privacy.

Health Information and Communication Systems. Easy consumer access to health information will be crucial for making a disease prevention/health promotion strategy work. Consumers will have greater health information available to them at home including clinical advice about specific diseases, information on their own health conditions and normal expectations, access to their own medical records, disease prevention/health promotion information geared to their individual health status, and access to evaluations of providers and therapies. Hypertext and hypermedia will be increasingly used to allow "layered access" to information: simple material for quick reference, more sophisticated material for those who want it, and access to supporting medical literature for those who want to find out all they can. Before 2010, AI "knowbot" technology will make it much easier for people to find the information they need. Interactive learning and communication technologies in the home setting are directly applicable to the need to achieve healthful life style behaviors and to encourage consumer self responsibility and informed health care decisions.

Health Outcome Measures. Major efforts are underway in Europe and the U.S. to develop health outcome measures. Electronic records will play a critical role, making it easy to gather and analyze large amounts of patient data. Ultimately health outcome measures will allow comparisons of the results of different health care providers and different therapies. Various kinds of outcome measures will be developed by different parties, including consumer organizations and companies that use consumer data. Today, local consumer-oriented rating systems conduct surveys to get general evaluations of consumer satisfaction with providers. This information is useful, but provides only a very limited perspective. As medical records become electronic, and large bodies of aggregated patient data are analyzed, consumer rating systems will be able to include measures of specific clinical success levels of alternative treatments and providers. Before 2010, health outcome measures are likely to play a significant role in exposing inappropriate medical practices and directing therapeutic selection.

Diagnostic and Therapeutic Expert Consultation Systems. In the 1980s, many expert systems for assisting in diagnosis were developed and used primarily as teaching devices. By 1995, expert systems are likely to be used increasingly on physicians' work stations for consultation and quality control. A similar pattern is likely for therapeutic consultation systems. In the 1990s they will be developed as "decision support" tools for providers that will perform functions such as suggesting the appropriate work-up testing sequence and treatment patterns for specific illnesses. In the late 1990s they will be linked to the electronic medical record and knowledge bases that will advise the practitioner on the logic and medical literature supporting specific decisions. Simplified versions of diagnostic and therapeutic expert systems, suitable for use by consumers, already exist in pilot form.

The Health Coach. The growing emphasis on disease prevention and health promotion is leading health care professionals to focus on their "coaching" role in encouraging health-promoting behavior. Software systems which function essentially as a coach to improve personal health and fitness can help health care professionals perform this role. Good software design, including artificial intelligence programming, can bring many of the psychological dynamics of effective coaching into the home setting.

Health Coach expert systems will emerge in the mid-1990s as an important new aspect of home health care. Health coaches will help to reinforce positive, healthy behaviors such as following a healthy diet, maintaining proper weight, stopping bad habits, and encouraging regular exercise. They will also increase compliance with therapies, helping patients to follow physician's instructions regarding medicines, home tests and treatments, appointments and other matters. After 2000, low cost voice recognition and synthesis will allow these expert systems to "talk" with family members. Ultimately they will be able to provide individually customized coaching based on past interactions with users, current health status information from users' electronic medical records, the learning styles, interests, and knowledge level of individual users, and regularly updated medical knowledge bases.

Automatic Alert and Monitoring Systems. Simple **emergency alert** systems are already widely available that allow home bound patients to call for help if they fall down or experience other emergency situations. By pressing a button on a light weight pendant around their neck or wrist, they are instantly connected through their telephone to their hospital, fire department, or other emergency response center of their choice. More sophisticated response systems will be able to operate automatically in health emergencies and transmit relevant information to the response center.

Body function monitoring devices are increasingly used in the home to allow health care providers to monitor the progress of patients. The Holter monitor, for example, already provides 24 hour EKGs. Devices designed to conduct post-surgical checkups send data on blood pressure, pulse and other vital signs. As more sophisticated monitoring technologies are deployed in home settings, they can be used for **evaluating treatment regimes.** For example, effects of medications can be monitored in the home and dosage levels calibrated to achieve the best result for each individual. **Automated treatment** by drug dispensing and other means is also possible in a home setting. Already, for example, adaptive pacemakers with built-in sensors are used to stabilize erratic heart rhythms and insulin pumps automatically provide diabetics their medication.

By the mid-1990s, low cost biosensors will promote growth in the use of home monitoring systems that will be linked, when appropriate, to computers in physicians offices and managed care organizations. Many new types of monitoring technologies are being explored, from laser technologies for noninvasive blood testing to devices that measure changes in bodily electrical fields. After 2000, monitoring systems are likely to be integral to prevention efforts as well as diagnosis and treatment. The major limit on the use of home monitoring systems will probably not be cost but the ability of individuals to place devices accurately and use them properly.

Wrist watches are already available that measure blood pressure and pulse rate. Portable, wrist watch-size devices will become available during the 1990s to perform a growing variety of diagnostic evaluations. Eventually they will probably include expert system modules, administer pharmaceuticals, and link by portable radio to physician offices. As the Institute for Alternative Futures forecast a decade ago, this line of technical development will eventually produce a virtual "Hospital on the Wrist" (HOW).

Three Examples of Emerging Applications

The examples below illustrate how three types of health applications in the home may evolve over time, bringing a variety of features together into an integrated set of capabilities. As in the area of education, these examples are an imaginative exercise. They are optimistic but plausible estimates of the kind of capabilities that could emerge in homes between now and 2010.

Example 1: Home Consultations and Decision Making

Today a person wanting help in adopting a healthier lifestyle or confronting a specific health care problem has two basic options in terms of getting help through emerging home information systems.

The first set of electronic tools on the market today are stand-alone systems that do not require communications links. This includes medical information available in magnetic and optical disk formats, and instructional videotapes that employ psychological strategies to reinforce healthy behavior.

The second set of tools available today to a limited number of people involves telecommunications and home terminals or PCs to bring in health information services from a variety of information providers. A pilot program offered by the Harvard Community Health Plan (HCHP) is presently the most sophisticated example of this approach. The HCHP provides an integrated health care system consisting of a health data base, a decision tree expert system, and asynchronous communications.

In the HCHP pilot project, a decision tree expert counseling system enables a person to pose a question about a specific health condition, to receive either an immediate answer or a response in the form of additional questions in order of the urgency of the situation indicated. Based on the person's answers, the system can generate an immediate voice contact with the patient by a health care professional or continue to pursue additional questions as it gathers data from the patient's responses until the patient is satisfied or recommendations are made as to actions to be taken including calling for an appointment or calling back within some specified time. These expert systems are based on consensually developed practice protocols created by health professionals.

Using asynchronous communications, patients can also direct questions to their health professionals, make appointments or communicate any other data they want their health professionals to know about. All of the patients' inquiries can be recorded in their medical records so that health professionals can maintain a picture over time of the patient's state of mind, their concerns, specific conditions treated and medications and therapies recommended.

By 2010, far more sophisticated forms of home consultation and decision making will be possible. For example, many patients will be able to consult with their doctors by video links, facilitating a more personalized consultation in which physicians can observe the body language and demeanor of their patients. Home care workers will be able to consult with their supervisors and peers, search out needed information and hold video conferences with family members and physicians and other supervisory personnel as needed. Social workers and physio-therapists will be able to monitor and coach their patients' exercise therapies or demonstrate how medication or other therapies are to be conducted.

Expert systems and health coaches will be able to integrate into their recommendations all the **individual information** in a person's medical record, which by 2010 will contain detailed information on medical history, individual genetic profile, individual biochemistry, and periodic results from many new forms of body function monitoring and testing. At the same time, these systems will include constantly updated **medical information**, such as comparative health outcomes of alternative treatments. Health care professionals working with these systems will be able to tailor their advice to the patient's specific life styles and life situations. For aiding individual learning and providing motivational support, expert decision and coaching systems will be able to select and display appropriate material from any medium, including video programming. For many people, video materials are easier to grasp and have a higher emotional impact than other forms of information.

Example 2: Responding to a Skin Blemish

Today a person with a skin blemish or rash and surrounding ache can consult a self-help book, or phone any one of several sources, including a medical advice line. A relatively small number of people can also query their health care provider on line, or use a PC to seek information by working with an on line health information service. By 1995, the book will have become a piece of software for some consumers, and the phone a "smart phone" or computer link for others. The medical records of growing numbers of people will be in electronic format.

By 2010, two-way video consulting could allow a doctor to examine the blemish without a physical visit. An artificial intelligence program could search for relevant diagnostic information, interacting through the networks with diagnostic and therapeutic expert systems. Diagnosis could be done taking into account a broad range of information about the person's genetic profile and biological uniqueness, environmental conditions and stress levels, all stored in electronic medical records in the home.

Example 3: Home Treatment

Today devices are available to monitor a limited number of body functions, at times transmitting the information to a health care provider. Information, consultation and supervision of home care workers is available through face to face contact. By 1995, the home health environment will already be changing rapidly with the spread of new forms of home tests and monitoring devices. "Smart phones" or low-cost terminals will provide access to voice, text, and graphics.

By 2010, interactive voice, data and imaging will be available. Video support groups and remote video consultations will be possible without requiring patients to leave their homes or offices. A medical revolution will have occurred in monitoring technology, allowing home care workers (or patients themselves) to obtain and transmit to their health care professional or laboratory comprehensive body function information. Monitoring technology will increasingly be miniaturized and portable, linked to home information systems and providers, in some cases via cellular radio. More sophisticated monitoring will allow health care personnel to monitor the impacts of medical treatment and adapt treatments for the best results. Automated treatment will be common for some diseases, with appropriate medications being administered in response to changing body chemistry. This too will be miniaturized in many cases, down to the HOW or "hospital on the wrist." Patient reminder systems will not only ensure that medications will be taken properly but they will accumulate records on how attentive patients are to their recommended regimens and whether some greater intervention is desirable to support their self help.

Rapidly rising costs, which many analysts fear will produce a health care crisis by the end of the century, could accelerate many of these developments. Emphases like better prevention-oriented health information, more self-care and supervised home care, and careful evaluation of treatment outcomes are among the best ways to cut health care costs without lowering the quality of care. On the other hand, a crisis in health care costs could make it more difficult to invest in consumer-oriented health information services.

These examples only begin to suggest the ultimate impact of emerging health information systems. We believe that as computer-based medical records come into place and health information consultation and monitoring systems spread into homes and physicians' offices over the next generation, the impacts on health care can be revolutionary.

These systems will put more science into every aspect of the art of medicine, from self-care in the home to the formulation of national health care policy. Over the long run, these systems can facilitate disease prevention and health promotion and allow the development of cost effectiveness and health outcome measures that can contain runaway costs. This would do more than any other single development today to improve health care for consumers.

NETWORK INFRASTRUCTURE REQUIREMENTS

Citizen access to the kind of advanced learning and health care services we have examined depends on the nature of the telecommunications infrastructure which is available.

Our goal in this section is to clarify for policy makers, consumer and telecommunications industry leaders and education and health care providers the four telecommunications network infrastructure elements -- 1) bandwidth, 2) interactivity, 3) switching and 4) access devices -- which will be required to deliver to the home the various health care and education applications discussed in the preceding sections.[9] Our intention is not to make recommendations among alternative infrastructure technologies, but rather to illustrate the different levels of infrastructure capability that are needed to provide different services.

1. Bandwidth

Most of the applications discussed in the preceding sections involve communications and require some type of "pipe" or line going into the home. These applications consist essentially of either voice only, graphics, data, video or a combination of these which are transmitted in and out of the home as "bits" of data. Voice communications involve relatively few bits of data while full motion video requires thousands or millions of bits of data to transmit.

The bandwidth or frequency span that a line can provide is related to its maximum rate of data transfer -- the amount of data that can be transmitted through the line in a given amount of time (e.g., bits per second or bps). Hence the bandwidth of the "pipe" coming into the home determines the type of communication which can be transmitted into and out of the home and the speed with which the communication can take place.

The precise bandwidth needed for different applications is hard to pin down definitively. Technology is highly dynamic and constantly developing. Moreover, acceptable bandwidths for given applications can vary widely depending on what image resolution, speed of data access or time delay in interactive communications is acceptable. It is necessary to keep these caveats in mind in the following discussion of particular bandwidths for particular applications.

NETWORK APPLICATIONS
By Bandwidth and Traffic Characteristics
FIGURE 3

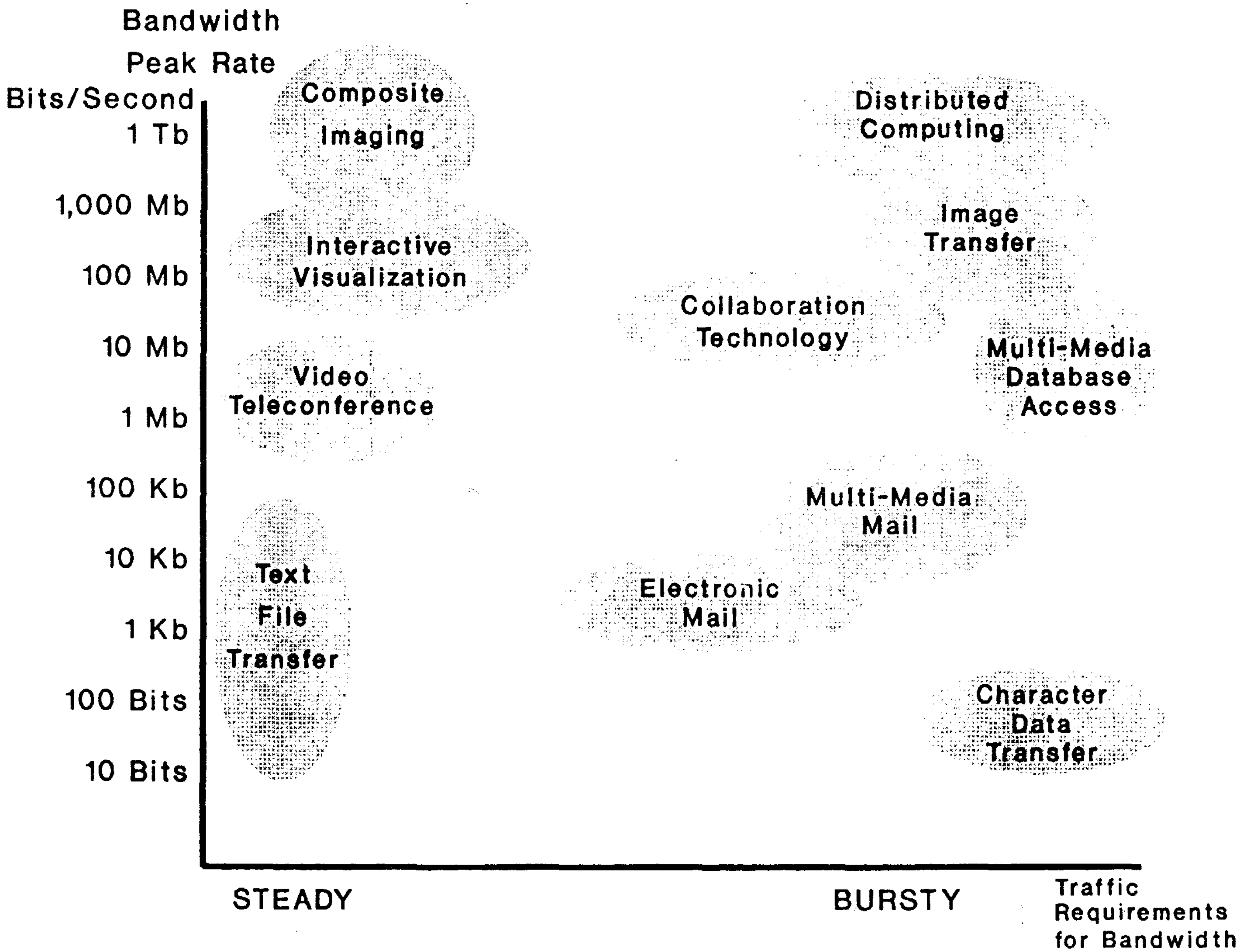


Figure 3 provides an overview of the bandwidth requirements of major generic network applications. Generic applications are the underlying applications that are used in every field. Transferring a text file, for example, is a generic application that is applied in myriad specific applications, from health and learning at home to business applications of all kinds. Four aspects of Figure 3 deserve close attention.

1) The generic applications in the mid-range of the chart -- video teleconferencing, collaboration technology, multi-media database access, and multi-media mail -- underlie most of the advanced learning and health applications we have reviewed. These generic applications require several orders of magnitude higher bandwidth than today's familiar generic applications such as transferring text files.

2) Each application is characterized in terms of a range of bandwidths or data rates that could be appropriate. For example, text file transfers can be done at rates varying from 10 bits per second (bps) to 100,000 bits per second (100 Kbps). Video teleconferencing can be done from several hundred Kbps to 10 million bits per second (10 Mbps). Faster data rates make possible quicker file transfers and higher quality video images.

3) The "traffic characteristics" of different applications vary widely. For example, a video teleconference, like a conventional phone call, produces a steady pattern of data flow. As long as the circuit is open, data keeps moving through it at a roughly constant rate. But other applications involve a bursty flow of data. In working with a multimedia database, for example, large "chunks" of information are downloaded quickly into a user's terminal and worked with for a while until other "chunks" are needed. As we will see, applications with bursty traffic requirements for bandwidth make especially strong demands for improvements in network switching as well as for high bandwidth lines reaching into the home.

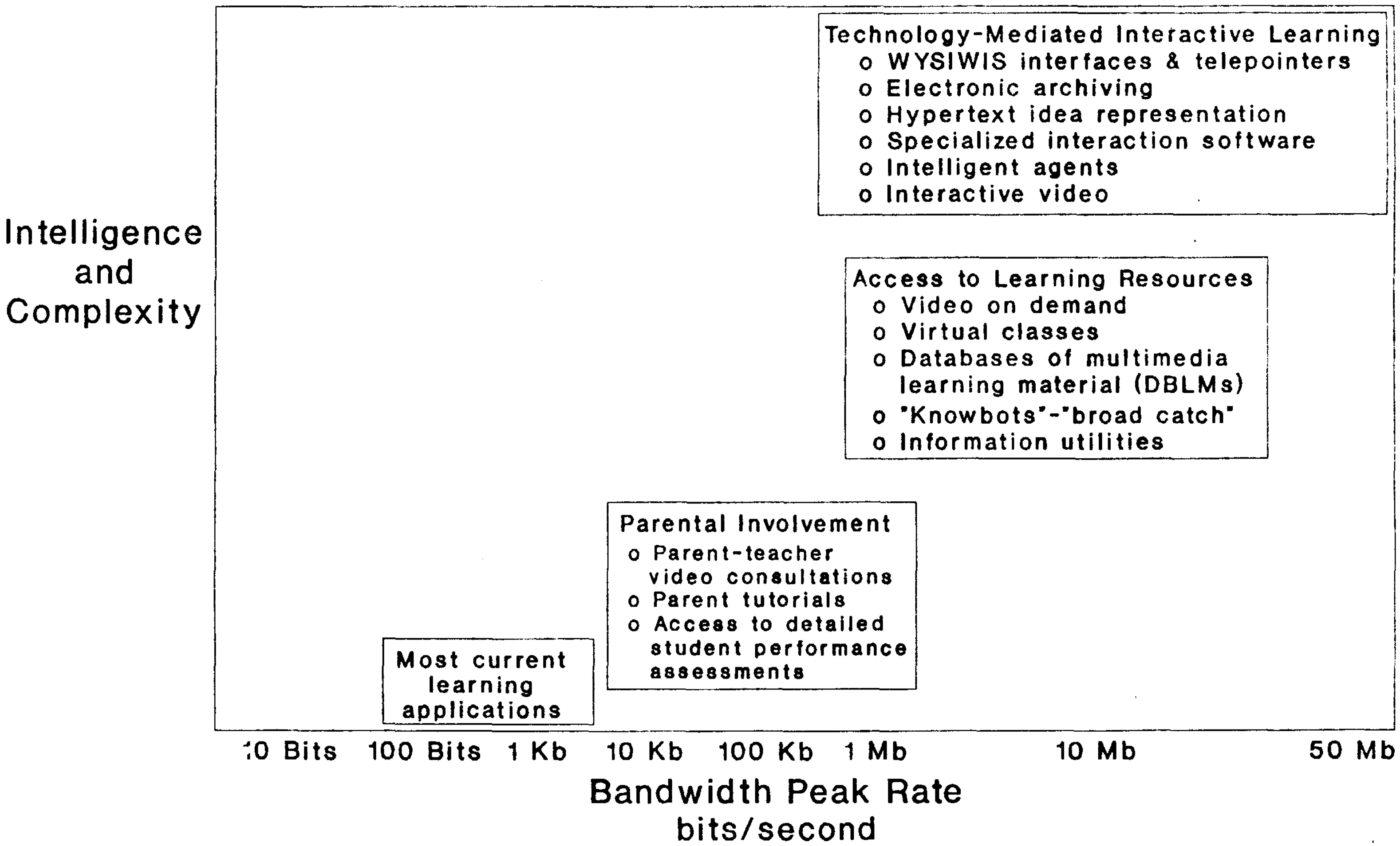
4) Applications at the top of Figure 3 such as composite imaging and distributed computing require data rates in the Gigabit range -- higher bandwidths than anything being contemplated for homes in this report. This is the bandwidth level that the National Research and Education Network (NREN) would provide to connect universities and other research centers.

Figure 4 illustrates the sharply escalating demands that several of the advanced learning applications we have examined will make for both bandwidth and "intelligence" or software complexity. Emerging applications like databases of multimedia learning materials and technology-mediated interactive learning arrangements clearly make very large demands for both bandwidth and intelligence compared to most current learning applications.

2010 HOME LEARNING APPLICATIONS

Escalating Demands for Bandwidth and Intelligence

FIGURE 4



A key consideration involved in bringing advanced learning and health applications into the home is the bandwidth capacity of the different types of lines or pipes going into the home. Each of the three principle types of lines which can come into the home today -- copper and enhanced copper wire, coaxial cable, and optical fiber -- are discussed below. A fourth alternative, radio, is discussed later.

Copper and Enhanced Copper: The twisted pair of copper wires in today's telephone lines have a data rate of 64 kbps and are capable either of carrying voice or of carrying data at relatively slow speeds into and out of the home. Thus today's telephone network can support a limited number of new health care and educational services such as providing parents with homework hotlines or transmitting medical data from body function monitoring devices. It can provide reasonably timely access to simple health care or educational databases and provide asynchronous electronic communications. But, for most of the more advanced applications described in the preceding sections involving the communication of high quality images or video, simultaneous voice and data, or high speed access to multimedia material, the current telephone wire does not provide sufficient bandwidth to enable these services to be accessible to and from the home.

However, there are new technologies which enable the amount of data that existing copper wire can carry to be increased -- ISDN, compression, and ASDL and HSDL.

Basic rate ISDN or Integrated Service Digital Network is a narrowband network architecture technology which speeds up data transmission and enables the current telephone line to carry voice and data communications simultaneously. Consisting of two 64 Kbps digital telephone channels and a 16 Kbps command channel, narrowband ISDN is being promoted currently as an interoffice business application to facilitate handling a voice telephone call simultaneously with sending a fax or sending or receiving data.

ISDN is also being promoted as an interim step which can facilitate public access to information services in a period before fiber optic cable can be widely deployed to the home. ISDN is projected by some to be widely available to residential subscribers by the later 1990s. If it proves to be an attractive option, the health or educational applications that require simultaneous voice and data communication could be provided over an ISDN enhanced telephone wire. A physician, for example, wanting to check a patient's vital signs remotely could give the patient both verbal and diagrammatic instructions as to where to place the monitoring instrument or how to use the prosthetic device or perform the prescribed therapy. Or students could listen to a lecture involving diagrammatic materials or present to their teachers or exchange with fellow students combined oral and written or graphic materials.

There is considerable controversy over the value of narrowband ISDN.[10] ISDN is expensive. It is only just being introduced as a business service and has not yet gained any significant market share, although some attribute this to delays in agreeing on a standard for ISDN, which until recently hindered software development and chilled the development of applications on PCs. Even in its current introductory stage as a business application, ISDN is seen as having a number of drawbacks. It cannot accommodate extension phones and cannot connect to the standard voice phone. It requires its own ISDN phone as well as an external power source. Moreover, just as with other efforts to enhance the bandwidth of copper wire, an ISDN solution to the limitations of copper wire is interim and carries its own substantial investment cost. Several of the panelists in the workshop we organized to review our preliminary findings characterized ISDN's improvements as, at best, marginal. Proponents of ISDN, on the other hand, argue that ISDN will prove increasingly attractive as new applications are developed for it. They see ISDN as the tip of the digital iceberg, the first step in a planned migration towards broadband transmission.

Image compression is a technology designed to enable reasonable quality pictures which normally require high bandwidth to be transmitted over much lower bandwidth lines. Very high image compression is possible; video compression technologies can already allow reasonable quality pictures to be transmitted over a basic rate ISDN channel (128 Kbps). Such high levels of compression are far too expensive for home use now: the required decompression circuits in home terminals would cost thousands of dollars. However some analysts believe that rapid progress in integrated circuit chips will bring these costs down quickly so that, by the late 1990s, image-oriented and even video applications could be flourishing based on low-rate ISDN.[11] Whatever types of "pipes" eventually go into the home, compression techniques are certain to play an important role.

While compression technologies can allow reasonably good images to be sent over phone lines, today they cannot be sent quickly. Some of our panelists thought the 8 to 10 second delay to transmit a good quality image would not be acceptable in many cases. Given that international satellite communications involve one-quarter of a second delay, our panelists were of the view that probably any more than one-half a second delay would be bothersome for many applications.

High Speed Digital Loop (HDSL) technology, currently being developed by Bellcore and industry vendors, is a new technology that can carry 1.5 Mbps on copper twisted pair (up to 10 Mbps over 4,000 feet) without requiring repeaters or other expensive changes in the outside plant. New electronics in the central office and in the home could allow a twisted pair to maintain basic phone service while also delivering a single compressed 1.5 Mbps video signal. This signal would have to be decompressed by TV circuitry or possibly by the decompression circuits that will first be available in the home in video CD players.

Another approach, Asymmetric Digital Loop (ADSL) technology, scheduled for trial in 1992, can give over 10,000 feet of copper wire a 1.5 Mbps one-way video channel, two 64 Kbps voice/data channels, and a 16 Kbps control channel. ADSL stretches copper wire to its outer limit. Like HDSL, it requires special electronics in the home. Both HDSL and ADSL are limited in terms of the length of copper wire which they can enhance. Both are essentially interim solutions for video needs pending the installation of fiber to the curb or to the home.

In addition to providing VCR picture quality video entertainment, one-way 1.5 Mbps video could support health care and educational applications such as video explanations of proper steps for home care treatments or documentaries related to students' course work. It could also permit one-way transmission of VCR-quality video out of the home, which might be valuable for some applications, but probably would not offer sufficiently high resolution to permit the remote examination of diagnostic images or other symptoms requiring visual interpretation. A 1.5 Mbps line could also support two-way low-resolution video that could make possible camcorder "televisits" even before video telephony becomes commonplace.

The economics of these approaches to putting 1.5 Mbps on copper wire are not well understood. If the costs prove reasonable for residential use, these approaches could substantially speed up low-end broadband availability. On the other hand, they cannot deliver bandwidth above 1.5 Mbps, and require considerable investment. They are interim solutions, and pose the difficult issue of when continued investment in interim solutions begins to delay the transition to a truly broadband network based on optical fiber.[12]

Coaxial Cable Networks: Cable today enjoys an actual and potential penetration of American households of 60% and 80% respectively. Cable networks have a one-way bandwidth capacity in excess of 200 Mbps and can transmit simultaneous voice, text and full motion video into the home. With the addition of limited interactivity in the form of a larger back channel from the home to the head end, cable could support limited data transmission out of the home. Some cable systems are being equipped to carry two-way voice traffic (e.g., Long Island, N.Y.)

Consumers using next generation cable systems will be able to send simple commands out of the home to call up desired multimedia materials such as health care or educational videos or data files providing information on hospitals, nursing homes and health care providers. However many health care and educational applications involve video and other communications out as well as into the home and require full interactivity and random addressability (anyone to anyone connections), which cannot be accommodated by coaxial cable systems today.

Fiber Optic Systems: Fiber optic cable has a bandwidth capacity far in excess of copper wire or cable. As the technology of choice for broadband networks, optical fiber is itself evolving rapidly. One forecaster estimates that the speed of a single strand of highest quality optical fiber will increase from 2.2 billion bits per second in the early 1990s to over 140 billion bps in 2000 and over 500 billion bps in 2010, which is near the ultimate physical limit.[13] Much slower speed fiber can carry enough bandwidth into the home to easily accomplish all the applications we have reviewed and many others. How fiber can best be connected to the home is a matter of considerable controversy that will be touched on in the next section.

Fiber is the only communications "pipe" that can carry the full range of advanced home learning and health care applications discussed above. Many of the 2010 examples such as parent-teacher and patient-provider consultations that benefit from 2-way live video become possible with fiber. Applications that require bulk transfer of groups of images also require the level of bandwidth that fiber (and coax) provide. For example, data rates ranging from a few Mbps to 45 Mbps are needed for taking blocks of material out of data bases of multimedia learning materials (DBLMs).

Technology-mediated interactive learning (TMIL) is potentially the most bandwidth hungry of all our 2010 examples. One applications developer anticipates screens that display multiple images in small windows -- participants in a video conference, a What You See is What I See (WYSIWIS) window, images from video files, documents. Touching a window would "open" it to fill much or all of the screen. Applications of this kind will require 10 Mbps with demand peaks as high as 45 Mbps.

In sum, the current necessity for residential broadband networks derives not only from the need to support particular bandwidth hungry services like one-way or two-way video but also from the raw speed required to multiplex a wide variety of low and medium bandwidth services in an increasingly interactive multimedia communications environment.

2. Interactivity

A second important feature of the various health care and educational applications discussed above is the degree of interactivity which they require.

"Interactivity" is one of those seemingly simple concepts that turn out to be surprisingly subtle when examined closely. At MIT's Media Lab, people working on "interactive" technologies have argued for years about what it means, developing a complex set of propositions and corollaries. The shorthand definition they all more or less accept is "Mutual and simultaneous activity on the part of both participants...." One of the participants can be a machine, or both participants can be human.[14]

In order to be clear about the requirements of applications for varying degrees of interactivity, we have specified four levels of interactivity.

1. No Interactivity. Most media we are familiar with fit in this category. From radio broadcasts at a low voice bandwidth, to newspapers and magazines with still images, to the higher bandwidth of broadcast, cable and DBS television with moving images, these are all "one way" media going into the home but not out. If there is no mutual and simultaneous activity, then there is no interactivity, no matter how high the bandwidth.

2. Full Interactivity with Limited Bandwidth. Applications involving exchange of voice communications and slow speed data transfers are characterized as fully interactive with

limited bandwidth. Most of the advanced health care and educational applications discussed above have bandwidth requirements which exceed this category of interactivity.

3. Limited Interactivity with High Bandwidth In and Low Bandwidth Out. Limited interactive applications are those which require one-way transmission of multimedia information into the home (voice, text, graphics, or full motion video) in response to relatively simple "command data" emanating from the home -- usually choices from a limited pre-programmed menu-- that specify the information to come back. Incoming information can be high bandwidth, such as video programming, but it is still limited interactivity if the back channel is limited. Using "talking yellow pages" or an online information service are examples of limited interactivity.

4. Full Interactivity with High Bandwidth. This level of interactivity allows multimedia communications, including full motion video in both directions. It requires a device in the home to capture the video image and high bandwidth out of the home as well as in.

Chart 1 groups examples of the learning and health applications we have examined into these four levels of interactivity.

CHART 1

INTERACTIVITY REQUIREMENTS OF SAMPLE APPLICATIONS

1. *No Interactivity*

   o None

2. *Full Interactivity With Limited Bandwidth*

   o Homework hotlines

   o Parent-teacher voice mail consultation

   o Medical advice lines

   o Links to health care provider - voice and text

   o Consultation, supervision for home care workers - voice and text

   o Transmission of body function monitoring data

3. *Limited Interactivity with High Bandwidth In and Low Bandwidth Out*

- o Detailed student performance records available on screen
- o Educational video on demand
- o Access to databases of multimedia learning materials (with limited menu-driven choices)
- o Access to diagnostic and therapeutic expert systems and regularly updated medical knowledge bases
- o Access to video/multimedia programming for helping people change their health behaviors

4. *Full Interactivity With High Bandwidth*

- o Parent-teacher video consultation
- o Teacher-student interactions in virtual classes
- o Technology-mediated interactive learning with groupware, teleconferencing, WYSIWIS interfaces, etc.
- o Highly interactive searching of databases of multimedia learning materials -- including information-searching "knowbots" and "broadcatch" of relevant material from multiple media
- o Transfer of computer-based medical records including images
- o AI searching of multimedia medical knowledge bases
- o Remote diagnostic evaluation of some medical conditions
- o Video communications with home bound patients, providing instructions, reassurance, etc.
- o Video support groups among patients
- o Video consultation, supervision for home care workers

Looking at advanced learning and health applications in terms of this framework suggests a number of insights.

First, conventional "no interactivity" media cannot support the health and learning applications of the future which all require communication out of the home as well as in.

Second, only a relatively small number of the learning and health applications we have examined can be handled by the "full interactivity with limited bandwidth" of the existing (unenhanced) telephone system. The telephone provides true "mutual and simultaneous activity" between two (or more) people, and can reach to everyone else who has a telephone. But it operates only at a low voice bandwidth and, when linked to a PC and modem, can only handle low speed transfer of text material. Telephones can provide important services, from homework hotlines to medical advice lines and the transmission of body function monitoring data. But they cannot handle more bandwidth-hungry applications such as face-to-face doctor-patient consultations or access to databases of multimedia learning materials.

Third, the category of "limited interactivity" with high bandwidth in but only simple command data out can support a larger number of applications such as access to multimedia databases of educational material or video health promotion programming. Any type of material that can be organized into easily definable categories and clear menu choices, requiring only limited amounts of data transmission out of the home, falls into this category. Because cable already supplies high bandwidth into many homes, and because cable systems are evolving in a way that will firm up the weak "back channel" that already exists in cable TV systems, cable may be better positioned than is commonly realized to provide many advanced learning and health services.

Fourth, the "full interactivity with high bandwidth" category encompasses many of the most effective approaches to learning and health care. Applications such as parent-teacher video conferences, teacher-student communications in "virtual classes," technology-mediated group learning, reassuring interactions between a doctor and home bound patient, or remote diagnostic evaluation of a medical condition require the high bandwidth, two-way interactions that fiber optic cable can provide.

At the present time, these full interactivity, high bandwidth applications could only be provided over specially dedicated fiber optic lines deployed between specific sites (e.g. medical image exchanges between hospitals and clinics, or advanced distance learning arrangements between educational institutions). While valuable, these institutional applications do not have a potential public benefit comparable to bringing these capabilities directly to the home -- and to schools and physician offices everywhere.

Until a nationwide fiber network is deployed, many of the most creative health care and educational applications cannot be made available to the general public because either the bandwidth or the true interactivity required by the applications does not exist. Even the most advanced applications, which may seem too far off to be concerned with today, will almost certainly be commonplace by 2000 to 2010 -- if a fiber network reaches into homes to make them available.

3. Switching

Switching (routing) is at the heart of modern telecommunications and is an integral part of many of the voice and data communication applications which we have been discussing. It is as critical an element in facilitating advanced telecommunications applications as are bandwidth and interactivity. It is switching that "makes the connection" between the consumer and the person or information service the consumer wants to deal with. It is the switching capability of a network which permits unprogrammed, spontaneous communications to any person or place from any other person or place.

Many of the learning and health applications we have examined involve switching between consumers and a set of limited sources (the school, the health care provider, a database). Many others, however, involve switching among all sources. For example, technology mediated interactive learning (TMIL) requires the capability to link up learners wherever they may be, as do support groups among patients and patients' families. Almost by definition, student initiated learning projects or student or patient random spontaneous access to libraries, experts or special interest organizations will be dependent upon their ability to exchange multimedia communications with others without the need for special designated lines or link-up arrangements.

Health care applications involving patient to patient or patient to health care professional will always involve spontaneous communications which cannot be predetermined. And patients, students, teachers and health care professionals are all essentially mobile. Teachers and physicians come and go and students and patients seldom have the same teachers and health care professionals for extended periods of time.

At this time, the telephone network is the only fully switched network that can accommodate anyone to anyone communications. Cable networks are not yet switched networks. A cable network operates essentially out of a single head end and site branching into the homes in a community. It can only handle simple command-type communications out of the home even though it can bring high bandwidth communication into the home.

The switching capacity of today's telephone networks is rapidly being upgraded by converting its analog switches to digital switching. This is as essential to the network's capacity to handle advanced health care and educational applications as is its bandwidth capacity. Bellcore has recently released a Technical Advisory for a SWIFT (SWItched Fractional T1) service to provide capabilities up to 1.5 Mbps through relatively inexpensive switch upgrades that can occur during the mid to late 1990s as networks become 100 percent digital.[15]

For providing advanced residential services, the most important emerging development is "fast packet switching." Today's networks have two different approaches to switching. Voice traffic typically uses "circuit switching," which holds a line open for the duration of a call. "Packet switching" networks are used to efficiently carry data traffic that comes in an uneven, bursty form. With packet switching, the line does not have to be held open. Data are separated into small packages or "packets" which are transmitted only when they are presented to the network. The packets are given a kind of "zip code" or destination address and routed individually along a variety of available paths, then reassembled at the receiving end in the correct sequence.

Current packet switches operate at thousands of packets per second, but fast or broadband switches will operate at millions of packets per second. At that speed, fast packet networks can packetize voice. While conventional packet switching is most suitable for routing data, fast packet switching will be able to switch voice, data and images in an integrated way. It will be the key tool for merging separate services into multimedia and for merging our different kinds of existing network fabrics into one. It will also be the key to providing bandwidth on demand, allowing users to get the bandwidth they need for each application, and no more. Bandwidth on demand will raise efficiency, reduce costs, and open the way for the full range of services into the home.[16]

Significant progress is underway on technology and standards for fast packet switching and broadband or B-ISDN. The so-called Synchronous Transfer Mode (ATM) is the next generation packet switch that will permit local exchange carriers to offer packet switching at multiple megabits per second rates. ATM will accommodate the SONET (Synchronous Optical Network) standard being developed by network standards bodies that will be the basis for broadband ISDN networks.[17] The SONET standard will route packets at speeds starting at 50 Mbps and going upward to hundreds of megabits per second.

Progress is also being made on ultra-fast optical switching, but there is a wide diversity of views about when optical switching will become important and what particular technical approach will come to the fore. None of the technical approaches being developed today are sufficiently advanced yet to challenge the preeminence of electronic switching.[18] Optical switching is not necessary to provide the services we have reviewed, even though it is a superior technology that will be used "when ready."

These high speed switching developments are of enormous significance for facilitating high speed multimedia communications. Progress in switching technology occurs "in the background" of the information infrastructure. Unlike terminals or even lines into the home, switches are invisible to users. Yet progress in switching is critical for bringing advanced learning and health applications into the home.

4. Terminals

Consumer information and communication services will only achieve their demand potential when both networks and terminal devices become so fast, easy and inexpensive to use that they are the most effective way to do key day-to-day tasks. Critical to consumer acceptance will be first, the technical capability of the terminal to process and handle graphics, imaging and interactive controls, second, their compatibility with other terminals and access devices, and third -- and even more important -- the extent to which they are affordable and easy to use.

Progress in terminals suitable for home use is essential. The key to their emerging role is the phenomenal rate of development of integrated circuit chips. Irwin Dorros, the executive vice president of Bellcore's Technical Services Sector, expresses a widely held view that telephone, computer and video technologies will merge during the 1990s into a new kind of "personal workstation." "Multimedia workstations more powerful than current ... workstation models will be available in ten years in the price range of today's TV sets."[19] An assessment of current developments for the European Community estimates that 25% of all desktop computers sold in 1995 will be multimedia-based and be able to process, manipulate, store and present full motion video.[20]

Given such dramatic price/performance improvements, the key challenge is to develop terminals for home use which are easy to use. User friendliness for the general public means in part "no waiting" for information you want to receive. Thus raw speed in both the terminal device and the network is a key factor in user friendliness. User friendliness also means "little difficulty" in doing what you want to do. In this area, the development of increasingly standardized graphical interfaces for applications of all kinds is an important factor. Handwriting recognition and touch screens will also become important over the next few years, especially in the use of portable terminals.

Between now and 2010, the pursuit of user friendliness will lead to more speed-intensive features such as high-resolution color flat screens, natural language processing, voice recognition, and knowledge robots -- all tools which can make it immeasurably easier for the public to use new learning and health applications.

How home terminals will evolve is, at this point, a matter of great uncertainty. Phillips, CitiBank and AT&T have already introduced a next generation "smart" telephone that offers many new functions, a display screen, and is exceptionally easy to use. Other types of "teleterminals" with larger screens and more capabilities are being designed. If more integrated home information services evolve first from cable, home terminals could be more TV-like; then, if regulators allow, a phone would be added. Personal computers, by far the most powerful terminals in homes today, are evolving rapidly toward digital image processing. Even powerful video game machines, with optical storage, and connected to cable or phone lines, could be a contender for providing information services in the 1990s home setting. Nintendo appears to be heading in this direction: in the U.S. it is focusing first on multiplayer games where players interact through the telephone network; in Japan it is pursuing a more direct strategy of adapting game machines to serve as home information appliances. And finally, if the U.S. chooses a digital approach to HDTV, television sets and computers will merge rapidly in the 1990s into a new kind of "teleputer" bringing what we now think of as mainframe level computing power into the nation's living rooms.

As we enter a new era of interactive multimedia, the previous concept of a low cost "dumb terminal" for home use is becoming obsolete. The real challenge is to develop "low-cost smart terminals", paying utmost attention to user-friendliness, and applying price/performance improvements to achieve that end. Multimedia terminals in the price range from a Minitel terminal ($79.00) to a medium priced TV set will be needed to extend advanced learning and health applications to the majority of the population.

This level of terminal price/performance is likely by the later 1990s. As a result, communication network development rather than terminals is likely to be the major bottleneck constricting home access to multimedia applications for learning, health and other areas. Later in the '90s, even tiny computers will spew out multimedia information at "fire hose" rates,[21] but many of them will connect to networks that only transmit information at "garden hose" rates. An enormous gap will emerge between the kind of multimedia applications available in corporations and other large institutions and what people will be able to do in their own homes. The resulting sense of frustration among consumers is likely to become a major consideration in telecommunications policymaking.

HOW INFORMATION COMES INTO THE HOME

Upgrading the existing telephone copper wire network or replacing copper with fiber optic cable in order to give the public access to the new information services, including the health care and educational applications discussed in this paper, presents one set of options to policy makers. Upgrading cable networks, cellular radio networks and direct broadcast satellites present other options.

Bringing optical fiber directly into the home to connect to home terminals would provide the public with access to maximum bandwidth. An important cost element in deploying fiber to the home, not present in copper wire enhancements, is the cost of the electronics in the home required to convert the optical signal as it comes into the home. At the present time, there are no reliable estimates of what the costs would be given the economies of scale which would result from national - or at least state wide - deployment of a fiber network.

An alternative approach that avoids these conversion costs for each home is to bring fiber to the "curb" (FTTC) or to the "pedestal." In this arrangement, the electronics for converting optical and electronic signals would be in an enclosure serving four to eight homes, with a "drop wire" running to each home. This approach would allow phone companies to upgrade the local loop to fiber while maintaining existing analog phone service and avoiding the electronic conversion expense for each home. In one scenario, the loop to each home from the pedestal could be rewired with coax or enhanced copper wire. In another scenario, consumers could choose, or not choose, to upgrade the electronic connection to their own home to bring in higher bandwidth services. Clearly, this alternative has very different cost implications for both consumers and telephone companies depending on how it is tariffed and very different social policy implications for universal access to the new information technologies.

The phone companies are looking at FTTC with great interest partly because it allows maintenance and administrative savings. For example, because fiber carries signals over long distances with low power loss, fiber would eliminate the need to service the repeaters or amplifiers along today's copper loop. But the cost implications for consumers also need to be explored.

Another concern with the FTTC approach is that configurations designed primarily to optimize ordinary phone service and capture savings for telephone companies may not be easy to upgrade later on to provide higher bandwidth access. In some architectures, the installed fiber would be little more than "silicon-based copper" and the cost of upgrading to higher bandwidth services in the home would be high.[22] An important issue for further consideration, therefore, is which of several possible FTTC architectures allow telephone